

*Physics**Physics Research Publications**Purdue University**Year 2010*

# Elliptic Flow of Charged Particles in Pb-Pb Collisions at $\sqrt{s(\text{NN})}=2.76$ TeV

K. Aamodt, B. Abelev, A. A. Quintana, D. Adamova, A. M. Adare, M. M. Aggarwal, G. A. Rinella, A. G. Agocs, S. A. Salazar, Z. Ahammed, A. A. Masoodi, N. Ahmad, S. U. Ahn, A. Akindinov, D. Aleksandrov, B. Alessandro, R. A. Molina, A. Alici, A. Alkin, E. A. Avina, T. Alt, V. Altini, S. Altinpinar, I. Altsybeev, C. Andrei, A. Andronic, V. Anguelov, C. Anson, T. Anticic, F. Antinori, P. Antonioli, L. Aphecetche, H. Appelshauser, N. Arbor, S. Arcelli, A. Arend, N. Armesto, R. Arnaldi, T. Aronsson, I. C. Arsene, A. Asryan, A. Augustinus, R. Auerbeck, T. C. Awes, J. Aysto, M. D. Azmi, M. Bach, A. Badala, Y. W. Baek, S. Bagnasco, R. Bailhache, R. Bala, R. B. Feroli, A. Baldissari, A. Baldit, F. B. D. Pedrosa, J. Ban, R. Barbera, F. Barile, G. G. Barnafoldi, L. S. Barnby, V. Barret, J. Bartke, M. Basile, N. Bastid, B. Bathen, G. Batigne, B. Batyunya, C. Baumann, I. G. Bearden, H. Beck, I. Belikov, F. Bellini, R. Bellwied, E. Belmont-Moreno, S. Beole, I. Berceanu, A. Bercuci, E. Berdermann, Y. Berdnikov, C. Bergmann, L. Betev, A. Bhasin, A. K. Bhati, L. Bianchi, N. Bianchi, C. Bianchin, J. Bielcik, J. Bielcikova, A. Bilandzic, E. Biolcati, A. Blanc, F. Blanco, D. Blau, C. Blume, M. Boccioli, N. Bock, A. Bogdanov, H. Boggild, M. Bogolyubsky, L. Boldizsar, M. Bombara, C. Bombonati, J. Book, H. Borel, A. Borissov, C. Bortolin, S. Bose, F. Bossu, M. Botje, S. Bottger, B. Boyer, P. Braun-Munzinger, L. Bravina, M. Bregant, T. Breitner, M. Broz, R. Brun, E. Bruna, G. E. Bruno, D. Budnikov, H. Buesching, K. Bugaiev, O. Busch, Z. Buthelezi, D. Caffarri, X. Cai, H. Caines, E. C. Villar, P. Camerini, V. C. Roman, G. C. Romeo, F. Carena, W. Carena, F. Carminati, A. C. Diaz, M. Caselle, J. C. Castellanos, V. Catanescu, C. Cavicchioli, J. Cepila, P. Cerello, B. Chang, S. Chapeland, J. L. Charvet, S. Chattopadhyay, M. Cherneny, C. Cheshkov, B. Cheynis, E. Chiavassa, V. C. Barroso, D. D. Chinellato, P. Chochula, M. Chojnacki, P. Christakoglou, C. H. Christensen, P. Christiansen, T. Chujo, C. Cicalo, L. Cifarelli, F. Cindolo, J. Cleymans, F. Coccetti, J. P. Coffin, S. Coli, G. C. Balbastre, Z. C. del Valle, P. Constantin, G. Contin, J. G. Contreras, T. M. Cormier, Y. C. Morales, I. C. Maldonado, P. Cortese, M.

R. Cosentino, F. Costa, M. E. Cotallo, E. Crescio, P. Crochet, E. Cuautle, L. Cunqueiro, G. D. Erasmo, A. Dainese, H. H. Dalsgaard, A. Danu, D. Das, I. Das, K. Das, A. Dash, S. Dash, S. De, A. D. Moregula, G. O. V. de Barros, A. De Caro, G. de Cataldo, J. de Cuveland, A. De Falco, D. De Gruttola, N. De Marco, S. De Pasquale, R. De Remigis, R. de Rooij, P. R. Debski, E. D. Sanchez, H. Delagrangé, Y. D. Mercado, G. Dellacasa, A. Deloff, V. Demanov, E. Denes, A. Deppman, D. Di Bari, C. Di Giglio, S. Di Liberto, A. Di Mauro, P. Di Nezza, T. Dietel, R. Divia, O. Djuvsland, A. Dobrin, T. Dobrowolski, I. Dominguez, B. Donigus, O. Dordic, O. Driga, A. K. Dubey, J. Dubuisson, L. Ducroux, P. Dupieux, A. K. D. Majumdar, M. R. D. Majumdar, D. Elia, D. Emschermann, H. Engel, H. A. Erdal, B. Espagnon, M. Estienne, S. Esumi, D. Evans, S. Evrard, G. Eyyubova, C. W. Fabjan, D. Fabris, J. Faivre, D. Falchieri, A. Fantoni, M. Fasel, R. Fearick, A. Fedunov, D. Fehlker, V. Fekete, D. Felea, G. Feofilov, A. F. Tellez, A. Ferretti, R. Ferretti, J. Figiel, M. A. S. Figueredo, S. Filchagin, R. Fini, D. Finogeev, F. M. Fionda, E. M. Fiore, M. Floris, S. Foertsch, P. Foka, S. Fokin, E. Fragiaco, M. Fragiadakis, U. Frankenfeld, U. Fuchs, F. Furano, C. Furget, M. F. Girard, J. J. Gaardhoje, S. Gadrat, M. Gagliardi, A. Gago, M. Gallio, D. R. Gangadharan, P. Ganoti, M. S. Ganti, C. Garabatos, E. Garcia-Solis, I. Garishvili, R. Gemme, J. Gerhard, M. Germain, C. Geuna, A. Gheata, M. Gheata, B. Ghidini, P. Ghosh, P. Gianotti, M. R. Girard, G. Giraudo, P. Giubellino, E. Gladysz-Dziadus, P. Glassel, R. Gomez, E. G. Ferreira, H. G. Santos, L. H. Gonzalez-Trueba, P. Gonzalez-Zamora, S. Gorbunov, S. Gotovac, V. Grabski, R. Grajcarek, A. Grelli, A. Grigoros, C. Grigoros, V. Grigoriev, A. Grigoryan, S. Grigoryan, B. Grinyov, N. Grion, P. Gros, J. F. Grosse-Oetringhaus, J. Y. Grossiord, R. Grosso, F. Guber, R. Guernane, C. G. Gutierrez, B. Guerzoni, K. Gulbrandsen, T. Gunji, A. Gupta, R. Gupta, H. Gutbrod, O. Haaland, C. Hadjidakis, M. Haiduc, H. Hamagaki, G. Hamar, J. W. Harris, M. Hartig, D. Hasch, D. Hasegan, D. Hatzifotiadou, A. Hayrapetyan, M. Heide, M. Heinz, H. Helstrup, A. Herghelegiu, C. Hernandez, G. H. Corral, N. Herrmann, K. F. Hetland, B. Hicks, P. T. Hille, B. Hippolyte, T. Horaguchi, Y. Hori, P. Hristov, I. Hrivnacova, M. Huang, S. Huber, T. J. Humanic, D. S. Hwang, R. Ichou, R. Ilkaev, I. Ilkiv, M. Inaba, E. Incani, G. M. Innocenti, P. G. Innocenti, M. Ippolitov, M. Irfan, C. Ivan, A. Ivanov, M. Ivanov, V. Ivanov, A. Jacholkowski, P. M. Jacobs, L. Jancurova, S. Jangal, R. Janik, S. Jena, L. Jirde, G. T. Jones, P. G. Jones, P. Jovanovic, H. Jung, W. Jung, A. Jusko, S. Kalcher, P. Kalinak, M. Kalisky, T. Kalliokoski, A. Kalweit, R. Kamermans, K. Kanaki, E. Kang, J. H. Kang, V. Kaplin, O. Karavichev, T. Karavicheva, E. Karpechev, A. Kazantsev, U. Kebschull, R. Keidel, M. M. Khan, S. A. Khan, A. Khanzadeev, Y. Kharlov, B. Kileng, D. J. Kim, D. S. Kim, D. W. Kim, H. N. Kim, J. H. Kim, J. S. Kim, M. Kim, S. Kim, S. H. Kim, S. Kirsch, I. Kisel, S. Kiselev, A. Kisiel, J. L. Klay, J. Klein, C. Klein-Bosing, M. Kliemant, A. Klovning, A. Kluge, M. L. Knichel, K. Koch, M. K. Kohler, R. Kolevatov, A. Kolojvari, V. Kondratiev, N. Kondratyeva, A. Konevskii, E. Kornas, C. K. K. Don, R. Kour, M. Kowalski, S. Kox, G. K. Meethalevedu, K. Kozlov, J. Kral, I. Kralik, F. Kramer, I. Kraus, T. Krawutschke, M. Kretz, M. Krivda, F. Krizek, D. Krumbhorn, M. Krus, E. Kryshen, M. Krzewicki, Y.

Kucheriaev, C. Kuhn, P. G. Kuijer, P. Kurashvili, A. Kurepin, A. B. Kurepin, A. Kuryakin, S. Kushpil, V. Kushpil, M. J. Kweon, Y. Kwon, P. La Rocca, P. L. de Guevara, V. Lafage, C. Lara, A. Lardeux, D. T. Larsen, C. Lazzeroni, Y. Le Bornec, R. Lea, K. S. Lee, S. C. Lee, F. Lefevre, J. Lehnert, L. Leistam, M. Lenhardt, V. Lenti, I. L. Monzon, H. L. Vargas, P. Levai, X. Li, J. Lien, R. Lietava, S. Lindal, V. Lindenstruth, C. Lippmann, M. A. Lisa, L. Liu, P. I. Loenne, V. R. Loggins, V. Loginov, S. Lohn, C. Loizides, K. K. Loo, X. Lopez, M. L. Noriega, E. L. Torres, G. Lovhoiden, X. G. Lu, P. Luettig, M. Lunardon, G. Luparello, L. Luquin, C. Luzzi, K. Ma, R. Ma, D. M. Madagodahettige-Don, A. Maevskaya, M. Mager, D. P. Mahapatra, A. Maire, D. Mal'Kevich, M. Malaev, I. M. Cervantes, L. Malinina, P. Malzacher, A. Mamonov, L. Manceau, L. Mangotra, V. Manko, F. Manso, V. Manzari, Y. Mao, J. Mares, G. V. Margagliotti, A. Margotti, A. Marin, C. Markert, I. Martashvili, P. Martinengo, M. I. Martinez, A. M. Davalos, G. M. Garcia, Y. Martynov, S. Masciocchi, M. Maser, A. Masoni, L. Massacrier, M. Mastromarco, A. Mastroserio, Z. L. Matthews, A. Matyja, D. Mayani, C. Mayer, G. Mazza, M. A. Mazzoni, F. Meddi, A. Menchaca-Rocha, P. M. Lorenzo, I. Menis, J. M. Perez, M. Meres, P. Mereu, Y. Miake, J. Midori, L. Milano, J. Milosevic, A. Mischke, D. Miskowicz, C. Mitu, J. Mlynarz, A. K. Mohanty, B. Mohanty, L. Molnar, L. M. Zetina, M. Monteno, E. Montes, M. Morando, D. A. M. De Godoy, S. Moretto, A. Morsch, V. Muccifora, E. Mudnic, S. Muhuri, H. Muller, M. G. Munhoz, J. Munoz, L. Musa, A. Musso, B. K. Nandi, R. Nania, E. Nappi, C. Natrass, F. Navach, S. Navin, T. K. Nayak, S. Nazarenko, G. Nazarov, A. Nedosekin, F. Nendaz, J. Newby, M. Nicassio, B. S. Nielsen, T. Niida, S. Nikolaev, V. Nikolic, S. Nikulin, V. Nikulin, B. S. Nilsen, M. S. Nilsson, F. Noferini, G. Nooren, N. Novitzky, A. Nyanin, A. Nyatha, C. Nygaard, J. Nystrand, H. Obayashi, A. Ochirov, H. Oeschler, S. K. Oh, J. Oleniacz, C. Oppedisano, A. O. Velasquez, G. Ortona, A. Oskarsson, P. Ostrowski, I. Otterlund, J. Otwinowski, K. Oyama, K. Ozawa, Y. Pachmayer, M. Pacher, F. Padilla, P. Pagano, S. P. Jayarathna, G. Paic, F. Painke, C. Pajares, S. Pal, S. K. Pal, A. Palaha, A. Palmeri, G. S. Pappalardo, W. J. Park, D. I. Patalakha, V. Patricchio, A. Pavlinov, T. Pawlak, T. Peitzmann, D. Peresunko, C. E. P. Lara, D. Perini, D. Perrino, W. Peryt, A. Pesci, V. Peskov, Y. Pestov, A. J. Peters, V. Petracek, M. Petran, M. Petris, P. Petrov, M. Petrovici, C. Petta, S. Piano, A. Piccotti, M. Pikna, P. Pillot, O. Pinazza, L. Pinsky, N. Pitz, F. Piuze, D. B. Piwarathna, R. Platt, M. Ploskon, J. Pluta, T. Pocheptsov, S. Pochybova, P. L. M. Podesta-Lerma, M. G. Poghosyan, K. Polak, B. Polichtchouk, A. Pop, S. Porteboeuf, V. Pospisil, B. Potukuchi, S. K. Prasad, R. Preghenella, F. Prino, C. A. Pruneau, I. Pshenichnov, G. Puodu, A. Pulvirenti, V. Punin, M. Putis, J. Putschke, E. Quercigh, H. Qvigstad, A. Rachevski, A. Rademakers, O. Rademakers, S. Radomski, T. S. Raiha, J. Rak, A. Rakotozafindrabe, L. Ramello, A. R. Reyes, M. Rammler, R. Raniwala, S. Raniwala, S. S. Rasanen, K. F. Read, J. Real, K. Redlich, R. Renfordt, A. R. Reolon, A. Reshetin, F. Rettig, J. P. Revol, K. Reygers, H. Ricard, L. Riccati, R. A. Ricci, M. Richter, R. Riedler, W. Riegler, F. Riggi, M. R. Cahuantzi, D. Rohr, D. Rohrich, R. Romita, F. Ronchetti, P. Rosinsky, P. Rosnet, S. Rossegger, A. Rossi, F. Roukoutakis, S. Rousseau, C. Roy, P. Roy, A. J. R. Montero, R.

Rui, A. Rivetti, I. Rusanov, E. Ryabinkin, A. Rybicki, S. Sadovsky, K. Safarik, R. Sahoo, P. K. Sahu, J. Saini, P. Saiz, S. Sakai, D. Sakata, C. A. Salgado, T. Samanta, S. Sambyal, V. Samsonov, X. S. Castro, L. Sandor, A. Sandoval, M. Sano, S. Sano, R. Santo, R. Santoro, J. Sarkamo, P. Saturnini, E. Scapparone, F. Scarlassara, R. P. Scharenberg, C. Schiaua, R. Schicker, C. Schmidt, H. R. Schmidt, S. Schreiner, S. Schuchmann, J. Schukraft, Y. Schutz, K. Schwarz, K. Schweda, G. Scioli, E. Scomparin, P. A. Scott, R. Scott, G. Segato, I. Seluzhenkov, S. Senyukov, J. Seo, S. Serchi, E. Serradilla, A. Sevcenco, I. Sgura, G. Shabratova, R. Shahoyan, N. Sharma, S. Sharma, K. Shigaki, M. Shimomura, K. Shtejer, Y. Sibiriyak, M. Siciliano, E. Sicking, T. Siemiarzczuk, A. Silenzi, D. Silvermyr, G. Simonetti, R. Singaraju, R. Singh, V. Singhal, B. C. Sinha, T. Sinha, B. Sitar, M. Sitta, T. B. Skaali, K. Skjerdal, R. Smakal, N. Smirnov, R. Snellings, C. Sogaard, A. Soloviev, R. Soltz, H. Son, J. Song, M. Song, C. Soos, F. Soramel, M. Spyropoulou-Stassinaki, B. K. Srivastava, J. Stachel, I. Stan, G. Stefanek, G. Stefanini, T. Steinbeck, M. Steinpreis, E. Stenlund, G. Steyn, D. Stocco, R. Stock, C. H. Stokkevag, M. Stolpovskiy, P. Strmen, A. A. P. Suaide, M. A. S. Vasquez, T. Sugitate, C. Suire, M. Sukhorukov, M. Sumbera, T. Susa, D. Swoboda, T. J. M. Symons, A. S. de Toledo, I. Szarka, A. Szostak, C. Tagridis, J. Takahashi, J. D. T. Takaki, A. Tauro, M. Tavlet, G. T. Munoz, A. Telesca, C. Terrevoli, J. Thader, D. Thomas, J. H. Thomas, R. Tieulent, A. R. Timmins, D. Tlusty, A. Toia, H. Torii, L. Toscano, F. Tosello, T. Traczyk, D. Truesdale, W. H. Trzaska, T. Tsuji, A. Tumkin, R. Turrisi, A. J. Turvey, T. S. Tveter, J. Ulery, K. Ullaland, A. Uras, J. Urban, G. M. Urciuoli, G. L. Usai, A. Vacchi, M. Vajzer, M. Vala, L. V. Palomo, S. Vallerio, N. van der Kolk, M. van Leeuwen, P. Vande Vyvre, L. Vannucci, A. Vargas, R. Varma, M. Vasileiou, A. Vasiliev, V. Vechernin, M. Veldhoen, M. Venaruzzo, E. Vercellin, S. Vergara, D. C. Vernekohl, R. Vernet, M. Verweij, L. Vickovic, G. Viesti, O. Vikhlyantsev, Z. Vilakazi, O. V. Baillie, A. Vinogradov, L. Vinogradov, Y. Vinogradov, T. Virgili, Y. P. Viyogi, A. Vodopyanov, K. Voloshin, S. Voloshin, G. Volpe, B. von Haller, D. Vranic, G. Ovrebekk, J. Vrlakova, B. Vulpescu, A. Vyushin, B. Wagner, V. Wagner, R. Wan, D. Wang, Y. Wang, K. Watanabe, J. P. Wessels, U. Westerhoff, J. Wiechula, J. Wikne, M. Wilde, A. Wilk, G. Wilk, M. C. S. Williams, B. Windelband, L. X. Karampatsos, H. Yang, S. Yang, S. Yasnopolskiy, J. Yi, Z. Yin, H. Yokoyama, I. K. Yoo, W. Yu, X. Yuan, I. Yushmanov, E. Zabrodin, C. Zach, C. Zampolli, S. Zaporozhets, A. Zarochentsev, P. Zavada, N. Zaviyalov, H. Zbroszczyk, P. Zelnicek, A. Zenin, I. Zgura, M. Zhalov, X. Zhang, D. Zhou, A. Zichichi, G. Zinovjev, Y. Zoccarato, and M. Zynovyev

This paper is posted at Purdue e-Pubs.

[http://docs.lib.purdue.edu/physics\\_articles/1126](http://docs.lib.purdue.edu/physics_articles/1126)



# Elliptic Flow of Charged Particles in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

K. Aamodt *et al.*\*

(ALICE Collaboration)

(Received 18 November 2010; published 13 December 2010)

We report the first measurement of charged particle elliptic flow in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV with the ALICE detector at the CERN Large Hadron Collider. The measurement is performed in the central pseudorapidity region ( $|\eta| < 0.8$ ) and transverse momentum range  $0.2 < p_t < 5.0$  GeV/c. The elliptic flow signal  $v_2$ , measured using the 4-particle correlation method, averaged over transverse momentum and pseudorapidity is  $0.087 \pm 0.002(\text{stat}) \pm 0.003(\text{syst})$  in the 40%–50% centrality class. The differential elliptic flow  $v_2(p_t)$  reaches a maximum of 0.2 near  $p_t = 3$  GeV/c. Compared to RHIC Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, the elliptic flow increases by about 30%. Some hydrodynamic model predictions which include viscous corrections are in agreement with the observed increase.

DOI: 10.1103/PhysRevLett.105.252302

PACS numbers: 25.75.Ld, 25.75.Gz, 25.75.Nq

The goal of ultrarelativistic nuclear collisions is the creation and study of the quark-gluon plasma (QGP), a state of matter whose existence at high energy density is predicted by quantum chromodynamics. One of the experimental observables that is sensitive to the properties of this matter is the azimuthal distribution of particles in the plane perpendicular to the beam direction. When nuclei collide at finite impact parameter (noncentral collisions), the geometrical overlap region and therefore the initial matter distribution is anisotropic (almond shaped). If the matter is interacting, this spatial asymmetry is converted via multiple collisions into an anisotropic momentum distribution [1]. The second moment of the final state hadron azimuthal distribution is called elliptic flow; it is a response of the dense system to the initial conditions and therefore sensitive to the early and hot, strongly interacting phase of the evolution.

At RHIC large elliptic flow has been observed and is one of the key experimental discoveries [2–6]. Theoretical models, based on ideal relativistic hydrodynamics with a QGP equation of state and zero shear viscosity, fail to describe elliptic flow measurements at lower energies but describe RHIC data reasonably well [7]. Theoretical arguments, based on the AdS/CFT conjecture [8], suggest a universal lower bound of  $1/4\pi$  [9] for the ratio of shear viscosity to entropy density. Recent model studies incorporating viscous corrections indicate that the shear viscosity at RHIC is within a factor of  $\sim 5$  of this bound [10–13].

The pure hydrodynamic models [7,14,15] and models which combine hydrodynamics with a hadron cascade afterburner (hybrid models) [16,17] that successfully de-

scribe flow at RHIC predict an increase of the elliptic flow at the LHC ranging from 10% to 30%, with the largest increase predicted by models which account for viscous corrections [15–18] at RHIC energies. In models with viscous corrections,  $v_2$  at RHIC is below the ideal hydrodynamic limit [12,17] and therefore can show a stronger increase with energy. In hydrodynamic models the charged particle elliptic flow as a function of transverse momentum does not change significantly [7,14], while the  $p_t$ -integrated elliptic flow increases due to the rise in average  $p_t$  expected from larger radial (azimuthally symmetric) flow. The larger radial flow also leads to a decrease of the elliptic flow at low transverse momentum, which is most pronounced for heavy particles. Models based on a parton cascade [19], including models that take into account quark recombination for particle production [20], predict a stronger decrease of the elliptic flow as a function of transverse momentum compared to RHIC energies. Phenomenological extrapolations [21] and models based on final state interactions [22] that have been tuned to describe the RHIC data predict an increase of the elliptic flow of  $\sim 50\%$ , larger than other models. A measurement of elliptic flow at the LHC is therefore crucial to test the validity of a hydrodynamic description of the medium and to measure its thermodynamic properties, in particular, shear viscosity and the equation of state [23].

The azimuthal dependence of the particle yield can be written in the form of a Fourier series [24,25]:

$$E \frac{d^3N}{d^3p} = \frac{1}{2\pi} \frac{d^2N}{p_t dp_t dy} \left( 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Psi_R)] \right), \quad (1)$$

where  $E$  is the energy of the particle,  $p$  the momentum,  $p_t$  the transverse momentum,  $\phi$  the azimuthal angle,  $y$  the rapidity, and  $\Psi_R$  the reaction plane angle. The reaction plane is the plane defined by the beam axis  $z$  and the impact parameter direction. In general the coefficients  $v_n = \langle \cos[n(\phi - \Psi_R)] \rangle$  are  $p_t$  and  $y$  dependent—therefore we

\*Full author list given at the end of the article.

refer to them as differential flow. The integrated flow is defined as an average evaluated with  $d^2N/dp_t dy$  used as a weight. The first coefficient,  $v_1$ , is called directed flow, and the second coefficient,  $v_2$ , is called elliptic flow.

We report the first measurement of elliptic flow of charged particles in Pb-Pb collisions at the center of mass energy per nucleon pair  $\sqrt{s_{NN}} = 2.76$  TeV, with the ALICE detector [26–28]. The data were recorded in November 2010 during the first run with heavy ions at the LHC.

For this analysis the ALICE inner tracking system (ITS) and the time projection chamber (TPC) were used to reconstruct the charged particle tracks. The VZERO counters and the silicon pixel detector (SPD) were used for the trigger. The VZERO counters are two scintillator arrays providing both amplitude and timing information, covering the pseudorapidity range  $2.8 < \eta < 5.1$  (VZERO-A) and  $-3.7 < \eta < -1.7$  (VZERO-C). The VZERO time resolution is better than 1 ns. The SPD is the innermost part of the ITS, consisting of two cylindrical layers of hybrid silicon pixel assemblies covering the range of  $|\eta| < 2.0$  and  $|\eta| < 1.4$  for the inner and outer layer, respectively. The minimum-bias interaction trigger required at least two out of the following three conditions [29]: (i) two pixel chips hit in the outer layer of the silicon pixel detectors, (ii) a signal in VZERO-A, (iii) a signal in VZERO-C. The bunch intensity was typically  $10^7$  Pb ions per bunch and each beam had 4 colliding bunches. The estimated luminosity was  $5 \times 10^{23} \text{ cm}^{-2} \text{ s}^{-1}$ , producing collisions with a minimum-bias trigger at a rate of 50 Hz including about 4 Hz nuclear interactions, 45 Hz electromagnetic processes, and 1 Hz beam background.

A removal of background events was carried out off-line using the VZERO timing information and the requirement of two tracks in the central detector. A study based on Glauber model fits to the multiplicity distribution (see also [29]) in the region corresponding to 80% of the most central collisions, where the vertex reconstruction is fully efficient, allows for the determination of the cross section percentile. Only events with a vertex found in  $|z| < 10$  cm were used in this analysis to ensure a uniform acceptance in the central pseudorapidity region  $|\eta| < 0.8$ . An event sample of  $45 \times 10^3$  Pb-Pb collisions passed the selection criteria and was used in this analysis. The data are analyzed in centrality classes determined by cuts on the uncorrected charged particle multiplicity, in pseudorapidity acceptance  $|\eta| < 0.8$ . Figure 1 shows the uncorrected charged particle multiplicity in the TPC for these events and indicates the nine centrality bins used in the analysis.

To select charged particles with high efficiency and to minimize the contribution from photon conversions and secondary charged particles produced in the detector material, the following track requirements were applied for tracks measured with the ITS and TPC. The tracks are required to have at least 70 reconstructed space points out

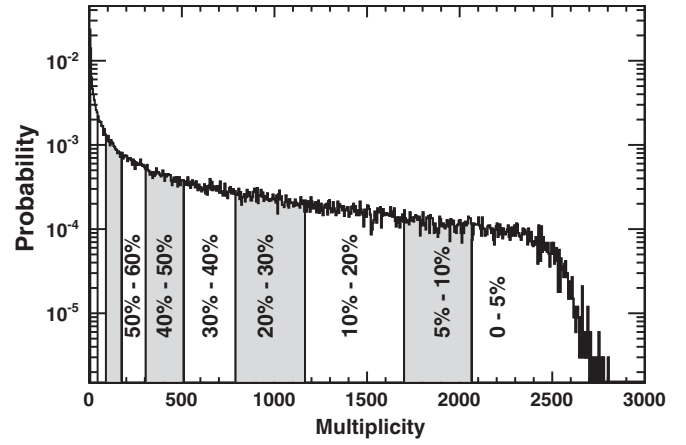


FIG. 1. The uncorrected multiplicity distribution of charged particles in the TPC ( $|\eta| < 0.8$ ). The centrality bins used in the analysis are shown and the cumulative fraction of the total events is indicated in percent. The bins 60%–70% and 70%–80% are not labeled.

of the maximum 159 in the TPC and a  $\langle \chi^2 \rangle$  per TPC cluster  $\leq 4$  (with 2 degrees of freedom per cluster). Additionally, at least two of the six ITS layers must have a hit associated with the track. Tracks are rejected if their distance of closest approach to the primary vertex is larger than 0.3 cm in the transverse plane and 0.3 cm in the longitudinal direction. For the selected tracks the reconstruction efficiency and remaining contamination are estimated by Monte Carlo simulations of HIJING [30] and THERMINATOR [31,32] events using a GEANT3 [33] detector simulation and event reconstruction. The reconstruction efficiency for tracks with  $0.2 < p_t < 1.0$  GeV/c increases from 60% to 70% after which it stays constant at  $(70 \pm 5)\%$ . The contamination from secondary interactions and photon conversions is less than 5% for  $p_t = 0.2$  GeV/c and less than 1% for  $p_t > 1$  GeV/c. Both the efficiency and contamination as a function of transverse momentum do not change significantly as a function of multiplicity and are therefore the same for all centrality classes.

An alternative analysis was performed with tracks reconstructed using only the TPC information. For these tracks the same selections were applied except for the requirement of hits in the ITS and allowing for a larger closest distance to the primary vertex, smaller than 3.0 cm in the transverse plane and 3.0 cm in the longitudinal direction. The reconstruction efficiency for these tracks with  $0.2 < p_t < 1.0$  GeV/c increases from 70% to 80% after which it stays constant at  $(80 \pm 5)\%$ . The contamination is less than 6% at  $p_t = 0.2$  GeV/c and drops below 1% at  $p_t > 1$  GeV/c. For this track selection the efficiency and contamination as a function of transverse momentum also do not depend significantly on the track density and are therefore the same for all centrality classes. The relative momentum resolution for tracks used in this analysis was better than 5%, both for the combined ITS-TPC and TPC stand-alone tracks. The results obtained from the



ITS-TPC and TPC stand-alone tracking are in excellent agreement. Because of the smaller corrections for the azimuthal acceptance, the results obtained using the TPC stand-alone tracks are presented in this Letter.

The  $p_t$ -differential flow was measured for different event centralities using various analysis techniques. In this Letter we report results obtained with 2- and 4-particle cumulant methods [34], denoted  $v_2\{2\}$  and  $v_2\{4\}$ . To calculate multiparticle cumulants we used a new fast and exact implementation [35]. The  $v_2\{2\}$  and  $v_2\{4\}$  measurements have different sensitivity to flow fluctuations and nonflow effects—which are uncorrelated to the initial geometry. Analytical estimates and results of simulations show that nonflow contributions to  $v_2\{4\}$  are negligible [36]. The contribution from flow fluctuations is positive for  $v_2\{2\}$  and negative for  $v_2\{4\}$  [37]. For the integrated elliptic flow we also fit the flow vector distribution [38] and use the Lee-Yang zeros method [39], which we denote by  $v_2\{q\text{-dist}\}$  and  $v_2\{\text{LYZ}\}$ , respectively [40]. In addition to comparing the 2- and 4-particle cumulant results we also estimate the nonflow contribution by comparing to correlations of particles of the same charge. Charge correlations due to processes contributing to nonflow (weak decays, correlations due to jets, etc.) lead to stronger correlations between particles of unlike charge sign than like charge sign.

Figure 2(a) shows  $v_2(p_t)$  for the centrality class 40%–50% obtained with different methods. For comparison, we present STAR measurements [41,42] for the same centrality from Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, indicated by the shaded area. We find that the value of  $v_2(p_t)$  does not change within uncertainties from  $\sqrt{s_{NN}} = 200$  GeV to 2.76 TeV. Figure 2(b) presents  $v_2(p_t)$  obtained with the 4-particle cumulant method for three different centralities, compared to STAR measurements. The transverse momentum dependence is qualitatively similar for all three centrality classes. At low  $p_t$  there is agreement of  $v_2(p_t)$  with STAR data within uncertainties.

The integrated elliptic flow is calculated for each centrality class using the measured  $v_2(p_t)$  together with the charged particle  $p_t$ -differential yield. For the determination of integrated elliptic flow the magnitude of the charged particle reconstruction efficiency does not play a role. However, the relative change in efficiency as a function of transverse momentum does matter. We have estimated the correction to the integrated elliptic flow based on HIJING and THERMINATOR simulations. Transverse momentum spectra in HIJING and THERMINATOR are different, giving an estimate of the uncertainty in the correction. The correction is about 2% with an uncertainty of 1%. In addition, the uncertainty due to the centrality determination results in a relative uncertainty of about 3% on the value of the elliptic flow.

Figure 3 shows that the integrated elliptic flow increases from central to peripheral collisions and reaches a

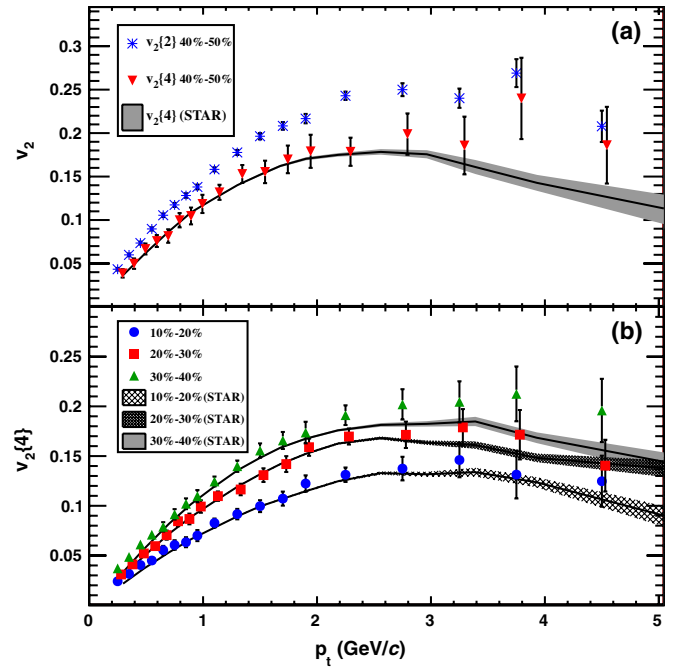


FIG. 2 (color online). (a)  $v_2(p_t)$  for the centrality bin 40%–50% from the 2- and 4-particle cumulant methods for this measurement and for Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. (b)  $v_2\{4\}(p_t)$  for various centralities compared to STAR measurements. The data points in the 20%–30% centrality bin are shifted in  $p_t$  for visibility.

maximum value in the 50%–60% and 40%–50% centrality class of  $0.106 \pm 0.001(\text{stat}) \pm 0.004(\text{syst})$  and  $0.087 \pm 0.002(\text{stat}) \pm 0.003(\text{syst})$  for the 2- and 4-particle cumulant method, respectively. It is also seen that the measured integrated elliptic flow from the 4-particle cumulant, from fits of the flow vector distribution, and from the Lee-Yang zeros method, are in agreement. The open markers in Fig. 3 show the results obtained for the cumulants using particles of the same charge. The 4-particle cumulant results agree within uncertainties for all charged particles and for the same charge particle data sets. The 2-particle cumulant results, as expected due to nonflow, depend weakly on the charge combination. The difference is most pronounced for the most peripheral and central events.

The integrated elliptic flow measured in the 20%–30% centrality class is compared to results from lower energies in Fig. 4. For the comparison we have corrected the integrated elliptic flow for the  $p_t$  cutoff of 0.2 GeV/c. The estimated magnitude of this correction is  $(12 \pm 5)\%$  based on calculations with THERMINATOR. The figure shows that there is a continuous increase in the magnitude of the elliptic flow for this centrality region from RHIC to LHC energies. In comparison to the elliptic flow measurements in Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, we observe about a 30% increase in the magnitude of  $v_2$  at  $\sqrt{s_{NN}} = 2.76$  TeV. The increase of about 30% is larger than in current ideal hydrodynamic calculations at LHC multiplic-

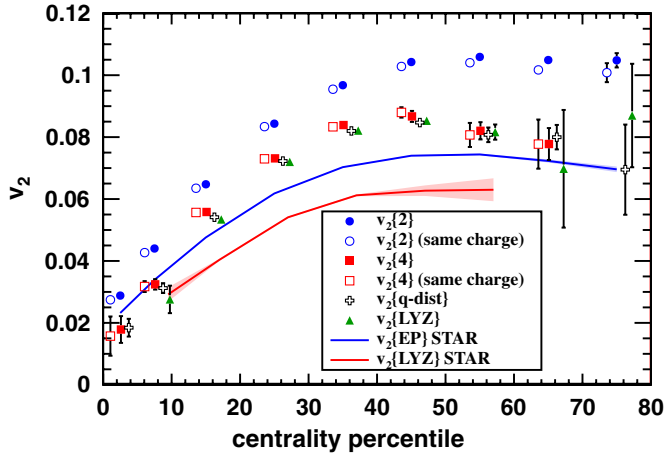


FIG. 3 (color online). Elliptic flow integrated over the  $p_t$  range  $0.2 < p_t < 5.0$  GeV/c, as a function of event centrality, for the 2- and 4-particle cumulant methods, a fit of the distribution of the flow vector, and the Lee-Yang zeros method. For the cumulants the measurements are shown for all charged particles (full markers) and same charge particles (open markers). Data points are shifted for visibility. RHIC measurements for Au-Au at  $\sqrt{s_{NN}} = 200$  GeV, integrated over the  $p_t$  range  $0.15 < p_t < 2.0$  GeV/c, for the event plane  $v_2\{EP\}$  and Lee-Yang zeros are shown by the solid curves.

ities [7] but is in agreement with some models that include viscous corrections which at the LHC become less important [12,15–18].

In summary we have presented the first elliptic flow measurement at the LHC. The observed similarity at RHIC and the LHC of  $p_t$ -differential elliptic flow at low  $p_t$  is consistent with predictions of hydrodynamic models [7,14]. We find that the integrated elliptic flow increases about 30% from  $\sqrt{s_{NN}} = 200$  GeV at RHIC to  $\sqrt{s_{NN}} =$

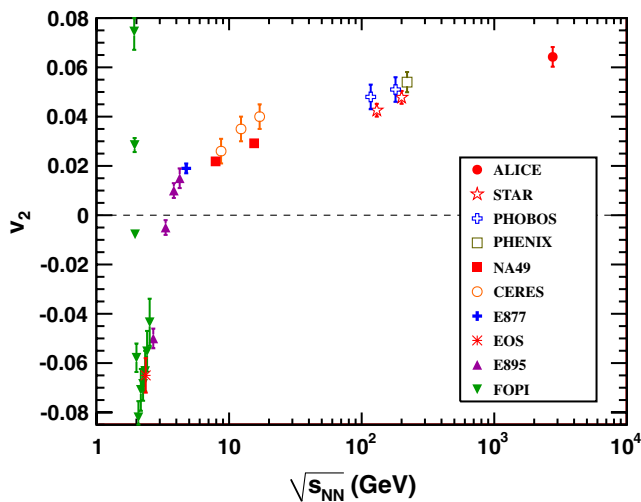


FIG. 4 (color online). Integrated elliptic flow at 2.76 TeV in Pb-Pb 20%–30% centrality class compared with results from lower energies taken at similar centralities [40,43].

2.76 TeV. The larger integrated elliptic flow at the LHC is caused by the increase in the mean  $p_t$ . Future elliptic flow measurements of identified particles will clarify the role of radial expansion in the formation of elliptic flow.

The ALICE Collaboration would like to thank all its engineers and technicians for their invaluable contributions to the construction of the experiment and the CERN accelerator teams for the outstanding performance of the LHC complex. The ALICE Collaboration acknowledges the following funding agencies for their support in building and running the ALICE detector: Calouste Gulbenkian Foundation from Lisbon and Swiss Fonds Kidagan, Armenia; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Financiadora de Estudos e Projetos (FINEP), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP); National Natural Science Foundation of China (NSFC), the Chinese Ministry of Education (CMOE), and the Ministry of Science and Technology of China (MSTC); Ministry of Education and Youth of the Czech Republic; Danish Natural Science Research Council, the Carlsberg Foundation, and the Danish National Research Foundation; The European Research Council under the European Community's Seventh Framework Programme; Helsinki Institute of Physics and the Academy of Finland; French CNRS-IN2P3, the “Region Pays de Loire,” “Region Alsace,” “Region Auvergne,” and CEA, France; German BMBF and the Helmholtz Association; Hungarian OTKA and National Office for Research and Technology (NKTH); Department of Atomic Energy and Department of Science and Technology of the Government of India; Istituto Nazionale di Fisica Nucleare (INFN) of Italy; MEXT Grant-in-Aid for Specially Promoted Research, Japan; Joint Institute for Nuclear Research, Dubna; National Research Foundation of Korea (NRF); CONACYT, DGAPA, México, ALFA-EC, and the HELEN Program (High-Energy physics Latin-American-European Network); Stichting voor Fundamenteel Onderzoek der Materie (FOM) and the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), Netherlands; Research Council of Norway (NFR); Polish Ministry of Science and Higher Education; National Authority for Scientific Research–NASR (Autoritatea Națională pentru Cercetare Științifică–ANCS); Federal Agency of Science of the Ministry of Education and Science of Russian Federation, International Science and Technology Center, Russian Academy of Sciences, Russian Federal Agency of Atomic Energy, Russian Federal Agency for Science and Innovations, and CERN–INTAS; Ministry of Education of Slovakia; CIEMAT, EELA, Ministerio de Educación y Ciencia of Spain, Xunta de Galicia (Consellería de Educación), CEADEN, Cubaenergía, Cuba, and IAEA (International Atomic Energy Agency); The Ministry of Science and Technology and the National Research Foundation



(NRF), South Africa; Swedish Research Council (VR) and Knut & Alice Wallenberg Foundation (KAW); Ukraine Ministry of Education and Science; United Kingdom Science and Technology Facilities Council (STFC); The U.S. Department of Energy, the U.S. National Science Foundation, the State of Texas, and the State of Ohio.

- 
- [1] J. Y. Ollitrault, *Phys. Rev. D* **46**, 229 (1992).  
 [2] K. H. Ackermann *et al.* (STAR Collaboration), *Phys. Rev. Lett.* **86**, 402 (2001).  
 [3] I. Arsene *et al.* (BRAHMS Collaboration), *Nucl. Phys. A* **757**, 1 (2005).  
 [4] B. B. Back *et al.* (PHOBOS Collaboration), *Nucl. Phys. A* **757**, 28 (2005).  
 [5] J. Adams *et al.* (STAR Collaboration), *Nucl. Phys. A* **757**, 102 (2005).  
 [6] K. Adcox *et al.* (PHENIX Collaboration), *Nucl. Phys. A* **757**, 184 (2005).  
 [7] G. Kestin and U. W. Heinz, *Eur. Phys. J. C* **61**, 545 (2009).  
 [8] J. M. Maldacena, *Adv. Theor. Math. Phys.* **2**, 231 (1998) [*Int. J. Theor. Phys.* **38**, 1113 (1999)].  
 [9] P. K. Kovtun, D. T. Son, and A. O. Starinets, *Phys. Rev. Lett.* **94**, 111601 (2005).  
 [10] D. Teaney, *Phys. Rev. C* **68**, 034913 (2003).  
 [11] P. Romatschke and U. Romatschke, *Phys. Rev. Lett.* **99**, 172301 (2007).  
 [12] H. Masui, J. Y. Ollitrault, R. Snellings, and A. Tang, *Nucl. Phys. A* **830**, 463C (2009).  
 [13] H. Song and U. W. Heinz, *J. Phys. G* **36**, 064033 (2009).  
 [14] H. Niemi, K. J. Eskola, and P. V. Ruuskanen, *Phys. Rev. C* **79**, 024903 (2009).  
 [15] M. Luzum and P. Romatschke, *Phys. Rev. Lett.* **103**, 262302 (2009).  
 [16] T. Hirano, P. Huovinen, and Y. Nara, [arXiv:1010.6222](#).  
 [17] T. Hirano, U. W. Heinz, D. Kharzeev, R. Lacey, and Y. Nara, *Phys. Lett. B* **636**, 299 (2006).  
 [18] H. J. Drescher, A. Dumitru, and J. Y. Ollitrault, [arXiv:0706.1707](#).  
 [19] D. Molnar, [arXiv:0707.1251](#).  
 [20] D. Krieg and M. Bleicher, *Phys. Rev. C* **78**, 054903 (2008).  
 [21] W. Busza, *J. Phys. G* **35**, 044040 (2008).  
 [22] A. Capella, E. G. Ferreira, A. Kaidalov, and K. Tywoniuk, [arXiv:0706.3315](#).  
 [23] N. Armesto *et al.*, *J. Phys. G* **35**, 054001 (2008).  
 [24] S. Voloshin and Y. Zhang, *Z. Phys. C* **70**, 665 (1996).  
 [25] A. M. Poskanzer and S. A. Voloshin, *Phys. Rev. C* **58**, 1671 (1998).  
 [26] ALICE Collaboration, *JINST* **3**, S08002 (2008).  
 [27] ALICE Collaboration, *J. Phys. G* **30**, 1517 (2004).  
 [28] ALICE Collaboration, *J. Phys. G* **32**, 1295 (2006).  
 [29] ALICE Collaboration, [arXiv:1011.3916](#).  
 [30] M. Gyulassy and X.-N. Wang, *Comput. Phys. Commun.* **83**, 307 (1994); X. N. Wang and M. Gyulassy, *Phys. Rev. D* **44**, 3501 (1991).  
 [31] A. Kisiel, T. Taluc, W. Broniowski, and W. Florkowski, *Comput. Phys. Commun.* **174**, 669 (2006).  
 [32] P. Bozek, M. Chojnacki, W. Florkowski, and B. Tomasik, *Phys. Lett. B* **694**, 238 (2010).  
 [33] R. Brun *et al.*, CERN Program Library Long Write-up, W5013, GEANT3 Detector Description and Simulation Tool, 1994.  
 [34] N. Borghini, P. M. Dinh, and J. Y. Ollitrault, *Phys. Rev. C* **64**, 054901 (2001).  
 [35] A. Bilandzic, R. Snellings, and S. Voloshin, [arXiv:1010.0233](#).  
 [36] C. Adler *et al.* (STAR Collaboration), *Phys. Rev. C* **66**, 034904 (2002).  
 [37] M. Miller and R. Snellings, [arXiv:nucl-ex/0312008](#).  
 [38] J. Adams *et al.* (STAR Collaboration), *Phys. Rev. Lett.* **93**, 252301 (2004).  
 [39] R. S. Bhalerao, N. Borghini, and J. Y. Ollitrault, *Nucl. Phys. A* **727**, 373 (2003).  
 [40] S. A. Voloshin, A. M. Poskanzer, and R. Snellings, in *Landolt-Boernstein, Relativistic Heavy Ion Physics* Vol. 1/23 (Springer-Verlag, Berlin, 2010), pp 5–54.  
 [41] Y. Bai, Ph.D. thesis, Nikhef and Utrecht University, 2007.  
 [42] B. I. Abelev *et al.* (STAR Collaboration), *Phys. Rev. C* **77**, 054901 (2008).  
 [43] A. Andronic *et al.* (FOPI Collaboration), *Phys. Lett. B* **612**, 173 (2005).
- 

K. Aamodt,<sup>1</sup> B. Abelev,<sup>2</sup> A. Abrahantes Quintana,<sup>3</sup> D. Adamová,<sup>4</sup> A. M. Adare,<sup>5</sup> M. M. Aggarwal,<sup>6</sup> G. Aglieri Rinella,<sup>7</sup> A. G. Agocs,<sup>8</sup> S. Aguilar Salazar,<sup>9</sup> Z. Ahammed,<sup>10</sup> A. Ahmad Masoodi,<sup>11</sup> N. Ahmad,<sup>11</sup> S. U. Ahn,<sup>12,b</sup> A. Akindinov,<sup>13</sup> D. Aleksandrov,<sup>14</sup> B. Alessandro,<sup>15</sup> R. Alfaro Molina,<sup>9</sup> A. Alici,<sup>16,c</sup> A. Alkin,<sup>17</sup> E. Almaráz Avila,<sup>9</sup> T. Alt,<sup>18</sup> V. Altini,<sup>19</sup> S. Altinpinar,<sup>20</sup> I. Altsybeev,<sup>21</sup> C. Andrei,<sup>22</sup> A. Andronic,<sup>20</sup> V. Anguelov,<sup>23,d</sup> C. Anson,<sup>24</sup> T. Antičić,<sup>25</sup> F. Antinori,<sup>26</sup> P. Antonioli,<sup>27</sup> L. Aphecetche,<sup>28</sup> H. Appelshäuser,<sup>29</sup> N. Arbor,<sup>30</sup> S. Arcelli,<sup>16</sup> A. Arend,<sup>29</sup> N. Armesto,<sup>31</sup> R. Arnaldi,<sup>15</sup> T. Aronsson,<sup>5</sup> I. C. Arsene,<sup>20</sup> A. Asryan,<sup>21</sup> A. Augustinus,<sup>7</sup> R. Averbeck,<sup>20</sup> T. C. Awes,<sup>32</sup> J. Äystö,<sup>33</sup> M. D. Azmi,<sup>11</sup> M. Bach,<sup>18</sup> A. Badalà,<sup>34</sup> Y. W. Baek,<sup>12</sup> S. Bagnasco,<sup>15</sup> R. Bailhache,<sup>29</sup> R. Bala,<sup>35,e</sup> R. Baldini Ferroli,<sup>36</sup> A. Baldissari,<sup>37</sup> A. Baldit,<sup>38</sup> F. Baltasar Dos Santos Pedrosa,<sup>7</sup> J. Bán,<sup>39</sup> R. Barbera,<sup>40</sup> F. Barile,<sup>19</sup> G. G. Barnaföldi,<sup>8</sup> L. S. Barnby,<sup>41</sup> V. Barret,<sup>38</sup> J. Bartke,<sup>42</sup> M. Basile,<sup>16</sup> N. Bastid,<sup>38</sup> B. Bathen,<sup>43</sup> G. Batigne,<sup>28</sup> B. Batyunya,<sup>44</sup> C. Baumann,<sup>29</sup> I. G. Bearden,<sup>45</sup> H. Beck,<sup>29</sup> I. Belikov,<sup>46</sup> F. Bellini,<sup>16</sup> R. Bellwied,<sup>47,f</sup> E. Belmont-Moreno,<sup>9</sup> S. Beole,<sup>35</sup> I. Berceanu,<sup>22</sup> A. Bercuci,<sup>22</sup> E. Berdermann,<sup>20</sup> Y. Berdnikov,<sup>48</sup> C. Bergmann,<sup>43</sup> L. Betev,<sup>7</sup> A. Bhasin,<sup>49</sup> A. K. Bhati,<sup>6</sup> L. Bianchi,<sup>35</sup> N. Bianchi,<sup>50</sup> C. Bianchin,<sup>26</sup> J. Bielčik,<sup>51</sup> J. Bielčíková,<sup>4</sup> A. Bilandzic,<sup>52</sup> E. Biolcati,<sup>35</sup> A. Blanc,<sup>38</sup> F. Blanco,<sup>53</sup> F. Blanco,<sup>54</sup> D. Blau,<sup>14</sup> C. Blume,<sup>29</sup> M. Boccioni,<sup>7</sup> N. Bock,<sup>24</sup> A. Bogdanov,<sup>55</sup> H. Bøggild,<sup>45</sup> M. Bogolyubsky,<sup>56</sup> L. Boldizsár,<sup>8</sup> M. Bombara,<sup>57</sup> C. Bombonati,<sup>26</sup> J. Book,<sup>29</sup>

- H. Borel,<sup>37</sup> A. Borissov,<sup>47</sup> C. Bortolin,<sup>26,g</sup> S. Bose,<sup>58</sup> F. Bossú,<sup>35</sup> M. Botje,<sup>52</sup> S. Böttger,<sup>23</sup> B. Boyer,<sup>59</sup> P. Braun-Munzinger,<sup>20</sup> L. Bravina,<sup>60</sup> M. Bregant,<sup>61,h</sup> T. Breitner,<sup>23</sup> M. Broz,<sup>62</sup> R. Brun,<sup>7</sup> E. Bruna,<sup>5</sup> G. E. Bruno,<sup>19</sup> D. Budnikov,<sup>63</sup> H. Buesching,<sup>29</sup> K. Bugaiev,<sup>17</sup> O. Busch,<sup>64</sup> Z. Buthelezi,<sup>65</sup> D. Caffarri,<sup>26</sup> X. Cai,<sup>66</sup> H. Caines,<sup>5</sup> E. Calvo Villar,<sup>67</sup> P. Camerini,<sup>61</sup> V. Canoa Roman,<sup>7,i</sup> G. Cara Romeo,<sup>27</sup> F. Carena,<sup>7</sup> W. Carena,<sup>7</sup> F. Carminati,<sup>7</sup> A. Casanova Díaz,<sup>50</sup> M. Caselle,<sup>7</sup> J. Castillo Castellanos,<sup>37</sup> V. Catanesu,<sup>22</sup> C. Cavicchioli,<sup>7</sup> J. Cepila,<sup>51</sup> P. Cerello,<sup>15</sup> B. Chang,<sup>33</sup> S. Chapeland,<sup>7</sup> J. L. Charvet,<sup>37</sup> S. Chattopadhyay,<sup>58</sup> S. Chattopadhyay,<sup>10</sup> M. Cherney,<sup>68</sup> C. Cheshkov,<sup>69</sup> B. Cheynis,<sup>69</sup> E. Chiavassa,<sup>15</sup> V. Chibante Barroso,<sup>7</sup> D. D. Chinellato,<sup>70</sup> P. Chochula,<sup>7</sup> M. Chojnacki,<sup>71</sup> P. Christakoglou,<sup>71</sup> C. H. Christensen,<sup>45</sup> P. Christiansen,<sup>72</sup> T. Chujo,<sup>73</sup> C. Cicalo,<sup>74</sup> L. Cifarelli,<sup>16</sup> F. Cindolo,<sup>27</sup> J. Cleymans,<sup>65</sup> F. Coccetti,<sup>36</sup> J.-P. Coffin,<sup>46</sup> S. Coli,<sup>15</sup> G. Conesa Balbastre,<sup>50,j</sup> Z. Conesa del Valle,<sup>28,k</sup> P. Constantin,<sup>64</sup> G. Contin,<sup>61</sup> J. G. Contreras,<sup>75</sup> T. M. Cormier,<sup>47</sup> Y. Corrales Morales,<sup>35</sup> I. Cortés Maldonado,<sup>76</sup> P. Cortese,<sup>77</sup> M. R. Cosentino,<sup>70</sup> F. Costa,<sup>7</sup> M. E. Cotallo,<sup>53</sup> E. Crescio,<sup>75</sup> P. Crochet,<sup>38</sup> E. Cuautle,<sup>78</sup> L. Cunqueiro,<sup>50</sup> G. D. Erasmo,<sup>19</sup> A. Dainese,<sup>79,l</sup> H. H. Dalsgaard,<sup>45</sup> A. Danu,<sup>80</sup> D. Das,<sup>58</sup> I. Das,<sup>58</sup> K. Das,<sup>58</sup> A. Dash,<sup>81</sup> S. Dash,<sup>15</sup> S. De,<sup>10</sup> A. De Azevedo Moregula,<sup>50</sup> G. O. V. de Barros,<sup>82</sup> A. De Caro,<sup>83</sup> G. de Cataldo,<sup>84</sup> J. de Cuveland,<sup>18</sup> A. De Falco,<sup>85</sup> D. De Gruttola,<sup>83</sup> N. De Marco,<sup>15</sup> S. De Pasquale,<sup>83</sup> R. De Remigis,<sup>15</sup> R. de Rooij,<sup>71</sup> P. R. Debski,<sup>86</sup> E. Del Castillo Sanchez,<sup>7</sup> H. Delagrange,<sup>28</sup> Y. Delgado Mercado,<sup>67</sup> G. Dellacasa,<sup>77,a</sup> A. Deloff,<sup>86</sup> V. Demanov,<sup>63</sup> E. Dénes,<sup>8</sup> A. Deppman,<sup>82</sup> D. Di Bari,<sup>19</sup> C. Di Giglio,<sup>19</sup> S. Di Liberto,<sup>87</sup> A. Di Mauro,<sup>7</sup> P. Di Nezza,<sup>50</sup> T. Dietel,<sup>43</sup> R. Divià,<sup>7</sup> Ø. Djuvsland,<sup>1</sup> A. Dobrin,<sup>47,m</sup> T. Dobrowolski,<sup>86</sup> I. Domínguez,<sup>78</sup> B. Dönigus,<sup>20</sup> O. Dordic,<sup>60</sup> O. Driga,<sup>28</sup> A. K. Dubey,<sup>10</sup> J. Dubuisson,<sup>7</sup> L. Ducroux,<sup>69</sup> P. Dupieux,<sup>38</sup> A. K. Dutta Majumdar,<sup>58</sup> M. R. Dutta Majumdar,<sup>10</sup> D. Elia,<sup>84</sup> D. Emschermann,<sup>43</sup> H. Engel,<sup>23</sup> H. A. Erdal,<sup>88</sup> B. Espagnon,<sup>59</sup> M. Estienne,<sup>28</sup> S. Esumi,<sup>73</sup> D. Evans,<sup>41</sup> S. Evrard,<sup>7</sup> G. Eyyubova,<sup>60</sup> C. W. Fabjan,<sup>7,n</sup> D. Fabris,<sup>89</sup> J. Faivre,<sup>30</sup> D. Falchieri,<sup>16</sup> A. Fantoni,<sup>50</sup> M. Fasel,<sup>20</sup> R. Fearick,<sup>65</sup> A. Fedunov,<sup>44</sup> D. Fehlker,<sup>1</sup> V. Fekete,<sup>62</sup> D. Felea,<sup>80</sup> G. Feofilov,<sup>21</sup> A. Fernández Téllez,<sup>76</sup> A. Ferretti,<sup>35</sup> R. Ferretti,<sup>77,o</sup> J. Figiel,<sup>42</sup> M. A. S. Figueredo,<sup>82</sup> S. Filchagin,<sup>63</sup> R. Fini,<sup>84</sup> D. Finogeev,<sup>90</sup> F. M. Fionda,<sup>19</sup> E. M. Fiore,<sup>19</sup> M. Floris,<sup>7</sup> S. Foertsch,<sup>65</sup> P. Foka,<sup>20</sup> S. Fokin,<sup>14</sup> E. Fragiaco,<sup>91</sup> M. Fragkiadakis,<sup>92</sup> U. Frankenfeld,<sup>20</sup> U. Fuchs,<sup>7</sup> F. Furano,<sup>7</sup> C. Furget,<sup>30</sup> M. Fusco Girard,<sup>83</sup> J. J. Gaardhøje,<sup>45</sup> S. Gadrat,<sup>30</sup> M. Gagliardi,<sup>35</sup> A. Gago,<sup>67</sup> M. Gallio,<sup>35</sup> D. R. Gangadharan,<sup>24</sup> P. Ganoti,<sup>92,p</sup> M. S. Ganti,<sup>10</sup> C. Garabatos,<sup>20</sup> E. Garcia-Solis,<sup>93</sup> I. Garishvili,<sup>2</sup> R. Gemme,<sup>77</sup> J. Gerhard,<sup>18</sup> M. Germain,<sup>28</sup> C. Geuna,<sup>37</sup> A. Gheata,<sup>7</sup> M. Gheata,<sup>7</sup> B. Ghidini,<sup>19</sup> P. Ghosh,<sup>10</sup> P. Gianotti,<sup>50</sup> M. R. Girard,<sup>94</sup> G. Giraudo,<sup>15</sup> P. Giubellino,<sup>35,q</sup> E. Gladysz-Dziadus,<sup>42</sup> P. Glässel,<sup>64</sup> R. Gomez,<sup>95</sup> E. G. Ferreira,<sup>31</sup> H. González Santos,<sup>76</sup> L. H. González-Trueba,<sup>9</sup> P. González-Zamora,<sup>53</sup> S. Gorbunov,<sup>18</sup> S. Gotovac,<sup>96</sup> V. Grabski,<sup>9</sup> R. Grajcarek,<sup>64</sup> A. Grelli,<sup>71</sup> A. Grigoras,<sup>7</sup> C. Grigoras,<sup>7</sup> V. Grigoriev,<sup>55</sup> A. Grigoryan,<sup>97</sup> S. Grigoryan,<sup>44</sup> B. Grinyov,<sup>17</sup> N. Grion,<sup>91</sup> P. Gros,<sup>72</sup> J. F. Grosse-Oetringhaus,<sup>7</sup> J.-Y. Grossiord,<sup>69</sup> R. Grosso,<sup>89</sup> F. Guber,<sup>90</sup> R. Guernane,<sup>30</sup> C. Guerra Gutierrez,<sup>67</sup> B. Guerzoni,<sup>16</sup> K. Gulbrandsen,<sup>45</sup> T. Gunji,<sup>98</sup> A. Gupta,<sup>49</sup> R. Gupta,<sup>49</sup> H. Gutbrod,<sup>20</sup> Ø. Haaland,<sup>1</sup> C. Hadjidakis,<sup>59</sup> M. Haiduc,<sup>80</sup> H. Hamagaki,<sup>98</sup> G. Hamar,<sup>8</sup> J. W. Harris,<sup>5</sup> M. Hartig,<sup>29</sup> D. Hasch,<sup>50</sup> D. Hasegan,<sup>80</sup> D. Hatzifotiadiou,<sup>27</sup> A. Hayrapetyan,<sup>97,o</sup> M. Heide,<sup>43</sup> M. Heinz,<sup>5</sup> H. Helstrup,<sup>88</sup> A. Herghelegiu,<sup>22</sup> C. Hernández,<sup>20</sup> G. Herrera Corral,<sup>75</sup> N. Herrmann,<sup>64</sup> K. F. Hetland,<sup>88</sup> B. Hicks,<sup>5</sup> P. T. Hille,<sup>5</sup> B. Hippolyte,<sup>46</sup> T. Horaguchi,<sup>73</sup> Y. Hori,<sup>98</sup> P. Hristov,<sup>7</sup> I. Hřivnáčová,<sup>59</sup> M. Huang,<sup>1</sup> S. Huber,<sup>20</sup> T. J. Humanic,<sup>24</sup> D. S. Hwang,<sup>99</sup> R. Ichou,<sup>28</sup> R. Ilkaev,<sup>63</sup> I. Ilkiv,<sup>86</sup> M. Inaba,<sup>86</sup> E. Incani,<sup>85</sup> G. M. Innocenti,<sup>35</sup> P. G. Innocenti,<sup>7</sup> M. Ippolitov,<sup>14</sup> M. Irfan,<sup>11</sup> C. Ivan,<sup>20</sup> A. Ivanov,<sup>21</sup> M. Ivanov,<sup>20</sup> V. Ivanov,<sup>48</sup> A. Jacholkowski,<sup>7</sup> P. M. Jacobs,<sup>100</sup> L. Jancurová,<sup>44</sup> S. Jangal,<sup>46</sup> R. Janik,<sup>62</sup> S. Jena,<sup>101</sup> L. Jirden,<sup>7</sup> G. T. Jones,<sup>41</sup> P. G. Jones,<sup>41</sup> P. Jovanović,<sup>41</sup> H. Jung,<sup>12</sup> W. Jung,<sup>12</sup> A. Jusko,<sup>41</sup> S. Kalcher,<sup>18</sup> P. Kaliňák,<sup>39</sup> M. Kalisky,<sup>43</sup> T. Kalliokoski,<sup>33</sup> A. Kalweit,<sup>102</sup> R. Kamermans,<sup>71,a</sup> K. Kanaki,<sup>1</sup> E. Kang,<sup>12</sup> J. H. Kang,<sup>103</sup> V. Kaplin,<sup>55</sup> O. Karavichev,<sup>90</sup> T. Karavicheva,<sup>90</sup> E. Karpechev,<sup>90</sup> A. Kazantsev,<sup>14</sup> U. Kebschull,<sup>23</sup> R. Keidel,<sup>104</sup> M. M. Khan,<sup>11</sup> S. A. Khan,<sup>10</sup> A. Khanzadeev,<sup>48</sup> Y. Kharlov,<sup>56</sup> B. Kileng,<sup>88</sup> D. J. Kim,<sup>33</sup> D. S. Kim,<sup>12</sup> D. W. Kim,<sup>12</sup> H. N. Kim,<sup>12</sup> J. H. Kim,<sup>99</sup> J. S. Kim,<sup>12</sup> M. Kim,<sup>12</sup> M. Kim,<sup>103</sup> S. Kim,<sup>99</sup> S. H. Kim,<sup>12</sup> S. Kirsch,<sup>7,r</sup> I. Kisel,<sup>23,s</sup> S. Kiselev,<sup>13</sup> A. Kisiel,<sup>7</sup> J. L. Klay,<sup>105</sup> J. Klein,<sup>64</sup> C. Klein-Bösing,<sup>43</sup> M. Kliemant,<sup>29</sup> A. Klovning,<sup>1</sup> A. Kluge,<sup>7</sup> M. L. Knichel,<sup>20</sup> K. Koch,<sup>64</sup> M. K. Köhler,<sup>20</sup> R. Kolevatov,<sup>60</sup> A. Kolojvari,<sup>21</sup> V. Kondratiev,<sup>21</sup> N. Kondratyeva,<sup>55</sup> A. Konevskih,<sup>90</sup> E. Kornás,<sup>42</sup> C. Kottachchi Kankanamge Don,<sup>47</sup> R. Kour,<sup>41</sup> M. Kowalski,<sup>42</sup> S. Kox,<sup>30</sup> G. Koyithatta Meethalevedu,<sup>101</sup> K. Kozlov,<sup>14</sup> J. Kral,<sup>33</sup> I. Králik,<sup>39</sup> F. Kramer,<sup>29</sup> I. Kraus,<sup>102,t</sup> T. Krawutschke,<sup>64,u</sup> M. Kretz,<sup>18</sup> M. Krivda,<sup>41,v</sup> F. Krizek,<sup>33</sup> D. Krumbhorn,<sup>64</sup> M. Krus,<sup>51</sup> E. Kryshen,<sup>48</sup> M. Krzewicki,<sup>52</sup> Y. Kucheriaev,<sup>14</sup> C. Kuhn,<sup>46</sup> P. G. Kuijer,<sup>52</sup> P. Kurashvili,<sup>86</sup> A. Kurepin,<sup>90</sup> A. B. Kurepin,<sup>90</sup> A. Kuryakin,<sup>63</sup> S. Kushpil,<sup>4</sup> V. Kushpil,<sup>4</sup> M. J. Kweon,<sup>64</sup> Y. Kwon,<sup>103</sup> P. La Rocca,<sup>40</sup> P. Ladrón de Guevara,<sup>53,w</sup> V. Lafage,<sup>59</sup> C. Lara,<sup>23</sup> A. Lardeux,<sup>28</sup> D. T. Larsen,<sup>1</sup> C. Lazzeroni,<sup>41</sup> Y. Le Bornec,<sup>59</sup> R. Lea,<sup>61</sup> K. S. Lee,<sup>12</sup> S. C. Lee,<sup>12</sup> F. Lefèvre,<sup>28</sup> J. Lehnert,<sup>29</sup> L. Leistam,<sup>7</sup> M. Lenhardt,<sup>28</sup> V. Lenti,<sup>84</sup>

- I. León Monzón,<sup>95</sup> H. León Vargas,<sup>29</sup> P. Lévai,<sup>8</sup> X. Li,<sup>106</sup> J. Lien,<sup>1</sup> R. Lietava,<sup>41</sup> S. Lindal,<sup>60</sup> V. Lindenstruth,<sup>23,s</sup> C. Lippmann,<sup>7,t</sup> M. A. Lisa,<sup>24</sup> L. Liu,<sup>1</sup> P. I. Loenne,<sup>1</sup> V. R. Loggins,<sup>47</sup> V. Loginov,<sup>55</sup> S. Lohn,<sup>7</sup> C. Loizides,<sup>100</sup> K. K. Loo,<sup>33</sup> X. Lopez,<sup>38</sup> M. López Noriega,<sup>59</sup> E. López Torres,<sup>3</sup> G. Løvholden,<sup>60</sup> X.-G. Lu,<sup>64</sup> P. Luettig,<sup>29</sup> M. Lunardon,<sup>26</sup> G. Luparello,<sup>35</sup> L. Luquin,<sup>28</sup> C. Luzzi,<sup>7</sup> K. Ma,<sup>66</sup> R. Ma,<sup>5</sup> D. M. Madagadhattige-Don,<sup>54</sup> A. Maevskaya,<sup>90</sup> M. Mager,<sup>7</sup> D. P. Mahapatra,<sup>81</sup> A. Maire,<sup>46</sup> D. Mal'Kevich,<sup>13</sup> M. Malaev,<sup>48</sup> I. Maldonado Cervantes,<sup>78</sup> L. Malinina,<sup>44,x</sup> P. Malzacher,<sup>20</sup> A. Mamonov,<sup>63</sup> L. Manceau,<sup>38</sup> L. Mangotra,<sup>49</sup> V. Manko,<sup>14</sup> F. Manso,<sup>38</sup> V. Manzari,<sup>84</sup> Y. Mao,<sup>66,y</sup> J. Mareš,<sup>107</sup> G. V. Margagliotti,<sup>61</sup> A. Margotti,<sup>27</sup> A. Marín,<sup>20</sup> C. Markert,<sup>108</sup> I. Martashvili,<sup>109</sup> P. Martinengo,<sup>7</sup> M. I. Martínez,<sup>76</sup> A. Martínez Davalos,<sup>9</sup> G. Martínez García,<sup>28</sup> Y. Martynov,<sup>17</sup> S. Masciocchi,<sup>20</sup> M. Maserà,<sup>35</sup> A. Masoni,<sup>74</sup> L. Massacrier,<sup>69</sup> M. Mastromarco,<sup>84</sup> A. Mastroserio,<sup>7</sup> Z. L. Matthews,<sup>41</sup> A. Matyja,<sup>28</sup> D. Mayani,<sup>78</sup> C. Mayer,<sup>42</sup> G. Mazza,<sup>15</sup> M. A. Mazzoni,<sup>87</sup> F. Meddi,<sup>110</sup> A. Menchaca-Rocha,<sup>9</sup> P. Mendez Lorenzo,<sup>7</sup> I. Menis,<sup>92</sup> J. Mercado Pérez,<sup>64</sup> M. Meres,<sup>62</sup> P. Mereu,<sup>15</sup> Y. Miake,<sup>73</sup> J. Midori,<sup>111</sup> L. Milano,<sup>35</sup> J. Milosevic,<sup>60,z</sup> A. Mischke,<sup>71</sup> D. Miśkowiec,<sup>20,q</sup> C. Mitu,<sup>80</sup> J. Mlynarz,<sup>47</sup> A. K. Mohanty,<sup>7</sup> B. Mohanty,<sup>10</sup> L. Molnar,<sup>7</sup> L. Montaña Zetina,<sup>75</sup> M. Monteno,<sup>15</sup> E. Montes,<sup>53</sup> M. Morando,<sup>26</sup> D. A. Moreira De Godoy,<sup>82</sup> S. Moretto,<sup>26</sup> A. Morsch,<sup>7</sup> V. Muccifora,<sup>50</sup> E. Mudnic,<sup>96</sup> S. Muhuri,<sup>10</sup> H. Müller,<sup>7</sup> M. G. Munhoz,<sup>82</sup> J. Munoz,<sup>76</sup> L. Musa,<sup>7</sup> A. Musso,<sup>15</sup> B. K. Nandi,<sup>101</sup> R. Nania,<sup>27</sup> E. Nappi,<sup>84</sup> C. Nattrass,<sup>109</sup> F. Navach,<sup>19</sup> S. Navin,<sup>41</sup> T. K. Nayak,<sup>10</sup> S. Nazarenko,<sup>63</sup> G. Nazarov,<sup>63</sup> A. Nedosekin,<sup>13</sup> F. Nendaz,<sup>69</sup> J. Newby,<sup>2</sup> M. Nicassio,<sup>19</sup> B. S. Nielsen,<sup>45</sup> T. Niida,<sup>73</sup> S. Nikolaev,<sup>14</sup> V. Nikolic,<sup>25</sup> S. Nikulin,<sup>14</sup> V. Nikulin,<sup>48</sup> B. S. Nilsen,<sup>68</sup> M. S. Nilsson,<sup>60</sup> F. Noferini,<sup>27</sup> G. Nooren,<sup>71</sup> N. Novitzky,<sup>33</sup> A. Nyanin,<sup>14</sup> A. Nyatha,<sup>101</sup> C. Nygaard,<sup>45</sup> J. Nystrand,<sup>1</sup> H. Obayashi,<sup>111</sup> A. Ochirov,<sup>21</sup> H. Oeschler,<sup>102</sup> S. K. Oh,<sup>12</sup> J. Oleniacz,<sup>94</sup> C. Oppedisano,<sup>15</sup> A. Ortiz Velasquez,<sup>78</sup> G. Ortona,<sup>35</sup> A. Oskarsson,<sup>72</sup> P. Ostrowski,<sup>94</sup> I. Otterlund,<sup>72</sup> J. Otwinowski,<sup>20</sup> K. Oyama,<sup>64</sup> K. Ozawa,<sup>98</sup> Y. Pachmayer,<sup>64</sup> M. Pachr,<sup>51</sup> F. Padilla,<sup>35</sup> P. Pagano,<sup>83</sup> S. P. Jayarathna,<sup>54,aa</sup> G. Paic,<sup>78</sup> F. Painke,<sup>18</sup> C. Pajares,<sup>31</sup> S. Pal,<sup>37</sup> S. K. Pal,<sup>10</sup> A. Palaha,<sup>41</sup> A. Palmeri,<sup>34</sup> G. S. Pappalardo,<sup>34</sup> W. J. Park,<sup>20</sup> D. I. Patalakha,<sup>56</sup> V. Patichio,<sup>84</sup> A. Pavlinov,<sup>47</sup> T. Pawlak,<sup>94</sup> T. Peitzmann,<sup>71</sup> D. Peresunko,<sup>14</sup> C. E. Pérez Lara,<sup>52</sup> D. Perini,<sup>7</sup> D. Perrino,<sup>19</sup> W. Peryt,<sup>94</sup> A. Pesci,<sup>27</sup> V. Peskov,<sup>7</sup> Y. Pestov,<sup>112</sup> A. J. Peters,<sup>7</sup> V. Petráček,<sup>51</sup> M. Petran,<sup>51</sup> M. Petris,<sup>22</sup> P. Petrov,<sup>41</sup> M. Petrovici,<sup>22</sup> C. Petta,<sup>40</sup> S. Piano,<sup>91</sup> A. Piccotti,<sup>15</sup> M. Pikna,<sup>62</sup> P. Pillot,<sup>28</sup> O. Pinazza,<sup>7</sup> L. Pinsky,<sup>54</sup> N. Pitz,<sup>29</sup> F. Piuze,<sup>7</sup> D. B. Piyarathna,<sup>47,bb</sup> R. Platt,<sup>41</sup> M. Płoskoń,<sup>100</sup> J. Pluta,<sup>94</sup> T. Pocheptsov,<sup>44,cc</sup> S. Pochybova,<sup>8</sup> P. L. M. Podesta-Lerma,<sup>95</sup> M. G. Poghosyan,<sup>35</sup> K. Polák,<sup>107</sup> B. Polichtchouk,<sup>56</sup> A. Pop,<sup>22</sup> S. Porteboeuf,<sup>38</sup> V. Pospíšil,<sup>51</sup> B. Potukuchi,<sup>49</sup> S. K. Prasad,<sup>47,dd</sup> R. Preghenella,<sup>36</sup> F. Prino,<sup>15</sup> C. A. Pruneau,<sup>47</sup> I. Pshenichnov,<sup>90</sup> G. Puddu,<sup>85</sup> A. Pulvirenti,<sup>40</sup> V. Punin,<sup>63</sup> M. Putiš,<sup>57</sup> J. Putschke,<sup>5</sup> E. Quercigh,<sup>7</sup> H. Qvigstad,<sup>60</sup> A. Rachevski,<sup>91</sup> A. Rademakers,<sup>7</sup> O. Rademakers,<sup>7</sup> S. Radomski,<sup>64</sup> T. S. Rähä,<sup>33</sup> J. Rak,<sup>33</sup> A. Rakotozafindrabe,<sup>37</sup> L. Ramello,<sup>77</sup> A. Ramírez Reyes,<sup>75</sup> M. Rammler,<sup>43</sup> R. Raniwala,<sup>113</sup> S. Raniwala,<sup>113</sup> S. S. Räsänen,<sup>33</sup> K. F. Read,<sup>109</sup> J. Real,<sup>30</sup> K. Redlich,<sup>86</sup> R. Renfordt,<sup>29</sup> A. R. Reolon,<sup>50</sup> A. Reshetin,<sup>90</sup> F. Rettig,<sup>18</sup> J.-P. Revol,<sup>7</sup> K. Reygers,<sup>64</sup> H. Ricaud,<sup>102</sup> L. Riccati,<sup>15</sup> R. A. Ricci,<sup>79</sup> M. Richter,<sup>1,ee</sup> P. Riedler,<sup>7</sup> W. Riegler,<sup>7</sup> F. Riggi,<sup>40</sup> M. Rodríguez Cahuantzi,<sup>76</sup> D. Rohr,<sup>18</sup> D. Röhrich,<sup>1</sup> R. Romita,<sup>20</sup> F. Ronchetti,<sup>50</sup> P. Rosinský,<sup>7</sup> P. Rosnet,<sup>38</sup> S. Rossegger,<sup>7</sup> A. Rossi,<sup>26</sup> F. Roukoutakis,<sup>92</sup> S. Rousseau,<sup>59</sup> C. Roy,<sup>28,k</sup> P. Roy,<sup>58</sup> A. J. Rubio Montero,<sup>53</sup> R. Rui,<sup>61</sup> A. Rivetti,<sup>15</sup> I. Rusanov,<sup>7</sup> E. Ryabinkin,<sup>14</sup> A. Rybicki,<sup>42</sup> S. Sadovsky,<sup>56</sup> K. Šafařík,<sup>7</sup> R. Sahoo,<sup>26</sup> P. K. Sahu,<sup>81</sup> J. Saini,<sup>10</sup> P. Saiz,<sup>7</sup> S. Sakai,<sup>100</sup> D. Sakata,<sup>73</sup> C. A. Salgado,<sup>31</sup> T. Samanta,<sup>10</sup> S. Sambyal,<sup>49</sup> V. Samsonov,<sup>48</sup> X. Sanchez Castro,<sup>78</sup> L. Šándor,<sup>39</sup> A. Sandoval,<sup>9</sup> M. Sano,<sup>73</sup> S. Sano,<sup>98</sup> R. Santo,<sup>43</sup> R. Santoro,<sup>84</sup> J. Sarkamo,<sup>33</sup> P. Saturnini,<sup>38</sup> E. Scapparone,<sup>27</sup> F. Scarlassara,<sup>26</sup> R. P. Scharenberg,<sup>114</sup> C. Schiaua,<sup>22</sup> R. Schicker,<sup>64</sup> C. Schmidt,<sup>20</sup> H. R. Schmidt,<sup>20</sup> S. Schreiner,<sup>7</sup> S. Schuchmann,<sup>29</sup> J. Schukraft,<sup>7</sup> Y. Schutz,<sup>28</sup> K. Schwarz,<sup>20</sup> K. Schweda,<sup>64</sup> G. Scioli,<sup>16</sup> E. Scomparin,<sup>15</sup> P. A. Scott,<sup>41</sup> R. Scott,<sup>109</sup> G. Segato,<sup>26</sup> I. Selyuzhenkov,<sup>20</sup> S. Senyukov,<sup>77</sup> J. Seo,<sup>12</sup> S. Serici,<sup>85</sup> E. Serradilla,<sup>53</sup> A. Sevcenco,<sup>80</sup> I. Sgura,<sup>84</sup> G. Shabratova,<sup>44</sup> R. Shahoyan,<sup>7</sup> N. Sharma,<sup>6</sup> S. Sharma,<sup>49</sup> K. Shigaki,<sup>111</sup> M. Shimomura,<sup>73</sup> K. Shtejer,<sup>3</sup> Y. Sibiriyak,<sup>14</sup> M. Siciliano,<sup>35</sup> E. Sickling,<sup>7</sup> T. Siemiarz,<sup>86</sup> A. Silenzi,<sup>16</sup> D. Silvermyr,<sup>32</sup> G. Simonetti,<sup>7,ff</sup> R. Singaraju,<sup>10</sup> R. Singh,<sup>49</sup> V. Singhal,<sup>10</sup> B. C. Sinha,<sup>10</sup> T. Sinha,<sup>58</sup> B. Sitar,<sup>62</sup> M. Sitta,<sup>77</sup> T. B. Skaali,<sup>60</sup> K. Skjerdal,<sup>1</sup> R. Smakal,<sup>51</sup> N. Smirnov,<sup>5</sup> R. Snellings,<sup>52,gg</sup> C. Sogaard,<sup>45</sup> A. Soloviev,<sup>56</sup> R. Soltz,<sup>2</sup> H. Son,<sup>99</sup> J. Song,<sup>115</sup> M. Song,<sup>103</sup> C. Soos,<sup>7</sup> F. Soramel,<sup>26</sup> M. Spyropoulou-Stassinaki,<sup>92</sup> B. K. Srivastava,<sup>114</sup> J. Stachel,<sup>64</sup> I. Stan,<sup>80</sup> G. Stefanek,<sup>86</sup> G. Stefanini,<sup>7</sup> T. Steinbeck,<sup>23,s</sup> M. Steinpreis,<sup>24</sup> E. Stenlund,<sup>72</sup> G. Steyn,<sup>65</sup> D. Stocco,<sup>28</sup> R. Stock,<sup>29</sup> C. H. Stokkevag,<sup>1</sup> M. Stolpovskiy,<sup>56</sup> P. Strmen,<sup>62</sup> A. A. P. Suaide,<sup>82</sup> M. A. Subieta Vásquez,<sup>35</sup> T. Sugitate,<sup>111</sup> C. Suire,<sup>59</sup> M. Sukhorukov,<sup>63</sup> M. Šumbera,<sup>4</sup> T. Susa,<sup>25</sup> D. Swoboda,<sup>7</sup> T. J. M. Symons,<sup>100</sup> A. Szanto de Toledo,<sup>82</sup> I. Szarka,<sup>62</sup> A. Szostak,<sup>1</sup> C. Tagridis,<sup>92</sup> J. Takahashi,<sup>70</sup> J. D. Tapia Takaki,<sup>59</sup> A. Tauro,<sup>7</sup> M. Tavlet,<sup>7</sup> G. Tejada Muñoz,<sup>76</sup> A. Telesca,<sup>7</sup> C. Terrevoli,<sup>19</sup> J. Thäder,<sup>20</sup> D. Thomas,<sup>71</sup> J. H. Thomas,<sup>20</sup> R. Tieulent,<sup>69</sup> A. R. Timmins,<sup>47,f</sup> D. Tlusty,<sup>51</sup>



A. Toia,<sup>7</sup> H. Torii,<sup>111</sup> L. Toscano,<sup>7</sup> F. Tosello,<sup>15</sup> T. Traczyk,<sup>94</sup> D. Truesdale,<sup>24</sup> W.H. Trzaska,<sup>33</sup> T. Tsuji,<sup>98</sup>  
 A. Tumkin,<sup>63</sup> R. Turrisi,<sup>89</sup> A.J. Turvey,<sup>68</sup> T.S. Tveter,<sup>60</sup> J. Ulery,<sup>29</sup> K. Ullaland,<sup>1</sup> A. Uras,<sup>85</sup> J. Urbán,<sup>57</sup>  
 G.M. Urciuoli,<sup>87</sup> G.L. Usai,<sup>85</sup> A. Vacchi,<sup>91</sup> M. Vajzer,<sup>51</sup> M. Vala,<sup>44,v</sup> L. Valencia Palomo,<sup>9,hh</sup> S. Vallero,<sup>64</sup>  
 N. van der Kolk,<sup>52</sup> M. van Leeuwen,<sup>71</sup> P. Vande Vyvre,<sup>7</sup> L. Vannucci,<sup>79</sup> A. Vargas,<sup>76</sup> R. Varma,<sup>101</sup> M. Vasileiou,<sup>92</sup>  
 A. Vasiliev,<sup>14</sup> V. Vechernin,<sup>21</sup> M. Veldhoen,<sup>71</sup> M. Venaruzzo,<sup>61</sup> E. Vercellin,<sup>35</sup> S. Vergara,<sup>76</sup> D.C. Vernekohl,<sup>43</sup>  
 R. Vernet,<sup>116</sup> M. Verweij,<sup>71</sup> L. Vickovic,<sup>96</sup> G. Viesti,<sup>26</sup> O. Vikhlyantsev,<sup>63</sup> Z. Vilakazi,<sup>65</sup> O. Villalobos Baillie,<sup>41</sup>  
 A. Vinogradov,<sup>14</sup> L. Vinogradov,<sup>21</sup> Y. Vinogradov,<sup>63</sup> T. Virgili,<sup>83</sup> Y.P. Viyogi,<sup>10</sup> A. Vodopyanov,<sup>44</sup> K. Voloshin,<sup>13</sup>  
 S. Voloshin,<sup>47</sup> G. Volpe,<sup>19</sup> B. von Haller,<sup>7</sup> D. Vranic,<sup>20</sup> G. Øvrebekk,<sup>1</sup> J. Vrláková,<sup>57</sup> B. Vulpescu,<sup>38</sup> A. Vyushin,<sup>63</sup>  
 B. Wagner,<sup>1</sup> V. Wagner,<sup>51</sup> R. Wan,<sup>46,ii</sup> D. Wang,<sup>66</sup> Y. Wang,<sup>64</sup> Y. Wang,<sup>66</sup> K. Watanabe,<sup>73</sup> J.P. Wessels,<sup>43</sup>  
 U. Westerhoff,<sup>43</sup> J. Wiechula,<sup>64</sup> J. Wikne,<sup>60</sup> M. Wilde,<sup>43</sup> A. Wilk,<sup>43</sup> G. Wilk,<sup>86</sup> M.C.S. Williams,<sup>27</sup> B. Windelband,<sup>64</sup>  
 L. Xaplanteris Karampatsos,<sup>108</sup> H. Yang,<sup>37</sup> S. Yang,<sup>1</sup> S. Yasnopolskiy,<sup>14</sup> J. Yi,<sup>115</sup> Z. Yin,<sup>66</sup> H. Yokoyama,<sup>73</sup>  
 I.-K. Yoo,<sup>115</sup> W. Yu,<sup>29</sup> X. Yuan,<sup>66</sup> I. Yushmanov,<sup>14</sup> E. Zabrodin,<sup>60</sup> C. Zach,<sup>51</sup> C. Zampolli,<sup>7</sup> S. Zaporozhets,<sup>44</sup>  
 A. Zarochentsev,<sup>21</sup> P. Závada,<sup>107</sup> N. Zaviyalov,<sup>63</sup> H. Zbroszczyk,<sup>94</sup> P. Zelnicek,<sup>23</sup> A. Zenin,<sup>56</sup> I. Zgura,<sup>80</sup> M. Zhalov,<sup>48</sup>  
 X. Zhang,<sup>66,b</sup> D. Zhou,<sup>66</sup> A. Zichichi,<sup>16,jj</sup> G. Zinovjev,<sup>17</sup> Y. Zoccarato,<sup>69</sup> and M. Zynovyev<sup>17</sup>

(ALICE Collaboration)

<sup>1</sup>Department of Physics and Technology, University of Bergen, Bergen, Norway

<sup>2</sup>Lawrence Livermore National Laboratory, Livermore, California, USA

<sup>3</sup>Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Havana, Cuba

<sup>4</sup>Nuclear Physics Institute, Academy of Sciences of the Czech Republic, Řež u Prahy, Czech Republic

<sup>5</sup>Yale University, New Haven, Connecticut, USA

<sup>6</sup>Physics Department, Panjab University, Chandigarh, India

<sup>7</sup>European Organization for Nuclear Research (CERN), Geneva, Switzerland

<sup>8</sup>KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences, Budapest, Hungary

<sup>9</sup>Instituto de Física, Universidad Nacional Autónoma de México, Mexico City, Mexico

<sup>10</sup>Variable Energy Cyclotron Centre, Kolkata, India

<sup>11</sup>Department of Physics Aligarh Muslim University, Aligarh, India

<sup>12</sup>Gangneung-Wonju National University, Gangneung, South Korea

<sup>13</sup>Institute for Theoretical and Experimental Physics, Moscow, Russia

<sup>14</sup>Russian Research Centre Kurchatov Institute, Moscow, Russia

<sup>15</sup>Sezione INFN, Turin, Italy

<sup>16</sup>Dipartimento di Fisica dell'Università and Sezione INFN, Bologna, Italy

<sup>17</sup>Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

<sup>18</sup>Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany

<sup>19</sup>Dipartimento Interateneo di Fisica "M. Merlin" and Sezione INFN, Bari, Italy

<sup>20</sup>Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

<sup>21</sup>V. Fock Institute for Physics, St. Petersburg State University, St. Petersburg, Russia

<sup>22</sup>National Institute for Physics and Nuclear Engineering, Bucharest, Romania

<sup>23</sup>Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

<sup>24</sup>Department of Physics, Ohio State University, Columbus, Ohio, USA

<sup>25</sup>Rudjer Bošković Institute, Zagreb, Croatia

<sup>26</sup>Dipartimento di Fisica dell'Università and Sezione INFN, Padova, Italy

<sup>27</sup>Sezione INFN, Bologna, Italy

<sup>28</sup>SUBATECH, Ecole des Mines de Nantes, Université de Nantes, CNRS-IN2P3, Nantes, France

<sup>29</sup>Institut für Kernphysik, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany

<sup>30</sup>Laboratoire de Physique Subatomique et de Cosmologie (LPSC), Université Joseph Fourier, CNRS-IN2P3,  
 Institut Polytechnique de Grenoble, Grenoble, France

<sup>31</sup>Departamento de Física de Partículas and IGFAE, Universidad de Santiago de Compostela, Santiago de Compostela, Spain

<sup>32</sup>Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

<sup>33</sup>Helsinki Institute of Physics (HIP) and University of Jyväskylä, Jyväskylä, Finland

<sup>34</sup>Sezione INFN, Catania, Italy

<sup>35</sup>Dipartimento di Fisica Sperimentale dell'Università and Sezione INFN, Turin, Italy

<sup>36</sup>Centro Fermi - Centro Studi e Ricerche e Museo Storico della Fisica "Enrico Fermi", Rome, Italy

<sup>37</sup>Commissariat à l'Energie Atomique, IRFU, Saclay, France

<sup>38</sup>Laboratoire de Physique Corpusculaire (LPC), Clermont Université, Université Blaise Pascal,  
 CNRS-IN2P3, Clermont-Ferrand, France

- <sup>39</sup>*Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia*  
<sup>40</sup>*Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Catania, Italy*  
<sup>41</sup>*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*  
<sup>42</sup>*The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland*  
<sup>43</sup>*Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, Münster, Germany*  
<sup>44</sup>*Joint Institute for Nuclear Research (JINR), Dubna, Russia*  
<sup>45</sup>*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*  
<sup>46</sup>*Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3, Strasbourg, France*  
<sup>47</sup>*Wayne State University, Detroit, Michigan, USA*  
<sup>48</sup>*Petersburg Nuclear Physics Institute, Gatchina, Russia*  
<sup>49</sup>*Physics Department, University of Jammu, Jammu, India*  
<sup>50</sup>*Laboratori Nazionali di Frascati, INFN, Frascati, Italy*  
<sup>51</sup>*Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic*  
<sup>52</sup>*Nikhef, National Institute for Subatomic Physics, Amsterdam, Netherlands*  
<sup>53</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*  
<sup>54</sup>*University of Houston, Houston, Texas, USA*  
<sup>55</sup>*Moscow Engineering Physics Institute, Moscow, Russia*  
<sup>56</sup>*Institute for High Energy Physics, Protvino, Russia*  
<sup>57</sup>*Faculty of Science, P. J. Šafárik University, Košice, Slovakia*  
<sup>58</sup>*Saha Institute of Nuclear Physics, Kolkata, India*  
<sup>59</sup>*Institut de Physique Nucléaire d'Orsay (IPNO), Université Paris-Sud, CNRS-IN2P3, Orsay, France*  
<sup>60</sup>*Department of Physics, University of Oslo, Oslo, Norway*  
<sup>61</sup>*Dipartimento di Fisica dell'Università and Sezione INFN, Trieste, Italy*  
<sup>62</sup>*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia*  
<sup>63</sup>*Russian Federal Nuclear Center (VNIIEF), Sarov, Russia*  
<sup>64</sup>*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*  
<sup>65</sup>*Physics Department, University of Cape Town, iThemba Laboratories, Cape Town, South Africa*  
<sup>66</sup>*Hua-Zhong Normal University, Wuhan, China*  
<sup>67</sup>*Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Lima, Peru*  
<sup>68</sup>*Physics Department, Creighton University, Omaha, Nebraska, USA*  
<sup>69</sup>*Université de Lyon, Université Lyon 1, CNRS/IN2P3, IPN-Lyon, Villeurbanne, France*  
<sup>70</sup>*Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil*  
<sup>71</sup>*Nikhef, National Institute for Subatomic Physics and Institute for Subatomic Physics of Utrecht University, Utrecht, Netherlands*  
<sup>72</sup>*Division of Experimental High Energy Physics, University of Lund, Lund, Sweden*  
<sup>73</sup>*University of Tsukuba, Tsukuba, Japan*  
<sup>74</sup>*Sezione INFN, Cagliari, Italy*  
<sup>75</sup>*Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico*  
<sup>76</sup>*Benemérita Universidad Autónoma de Puebla, Puebla, Mexico*  
<sup>77</sup>*Dipartimento di Scienze e Tecnologie Avanzate dell'Università del Piemonte Orientale and Gruppo Collegato INFN, Alessandria, Italy*  
<sup>78</sup>*Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico City, Mexico*  
<sup>79</sup>*Laboratori Nazionali di Legnaro, INFN, Legnaro, Italy*  
<sup>80</sup>*Institute of Space Sciences (ISS), Bucharest, Romania*  
<sup>81</sup>*Institute of Physics, Bhubaneswar, India*  
<sup>82</sup>*Universidade de São Paulo (USP), São Paulo, Brazil*  
<sup>83</sup>*Dipartimento di Fisica "E. R. Caianiello" dell'Università and Gruppo Collegato INFN, Salerno, Italy*  
<sup>84</sup>*Sezione INFN, Bari, Italy*  
<sup>85</sup>*Dipartimento di Fisica dell'Università and Sezione INFN, Cagliari, Italy*  
<sup>86</sup>*Soltan Institute for Nuclear Studies, Warsaw, Poland*  
<sup>87</sup>*Sezione INFN, Rome, Italy*  
<sup>88</sup>*Faculty of Engineering, Bergen University College, Bergen, Norway*  
<sup>89</sup>*Sezione INFN, Padova, Italy*  
<sup>90</sup>*Institute for Nuclear Research, Academy of Sciences, Moscow, Russia*  
<sup>91</sup>*Sezione INFN, Trieste, Italy*  
<sup>92</sup>*Physics Department, University of Athens, Athens, Greece*  
<sup>93</sup>*Chicago State University, Chicago, Illinois, USA*  
<sup>94</sup>*Warsaw University of Technology, Warsaw, Poland*  
<sup>95</sup>*Universidad Autónoma de Sinaloa, Culiacán, Mexico*  
<sup>96</sup>*Technical University of Split FESB, Split, Croatia*  
<sup>97</sup>*Yerevan Physics Institute, Yerevan, Armenia*  
<sup>98</sup>*University of Tokyo, Tokyo, Japan*

- <sup>99</sup>*Department of Physics, Sejong University, Seoul, South Korea*  
<sup>100</sup>*Lawrence Berkeley National Laboratory, Berkeley, California, USA*  
<sup>101</sup>*Indian Institute of Technology, Mumbai, India*  
<sup>102</sup>*Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*  
<sup>103</sup>*Yonsei University, Seoul, South Korea*  
<sup>104</sup>*Zentrum für Technologietransfer und Telekommunikation (ZTT), Fachhochschule Worms, Worms, Germany*  
<sup>105</sup>*California Polytechnic State University, San Luis Obispo, California, USA*  
<sup>106</sup>*China Institute of Atomic Energy, Beijing, China*  
<sup>107</sup>*Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*  
<sup>108</sup>*Physics Department, The University of Texas at Austin, Austin, Texas, USA*  
<sup>109</sup>*University of Tennessee, Knoxville, Tennessee, USA*  
<sup>110</sup>*Dipartimento di Fisica dell'Università "La Sapienza" and Sezione INFN, Rome, Italy*  
<sup>111</sup>*Hiroshima University, Hiroshima, Japan*  
<sup>112</sup>*Budker Institute for Nuclear Physics, Novosibirsk, Russia*  
<sup>113</sup>*Physics Department, University of Rajasthan, Jaipur, India*  
<sup>114</sup>*Purdue University, West Lafayette, Indiana, USA*  
<sup>115</sup>*Pusan National University, Pusan, South Korea*  
<sup>116</sup>*Centre de Calcul de l'IN2P3, Villeurbanne, France*

<sup>a</sup>Deceased.

<sup>b</sup>Also at Laboratoire de Physique Corpusculaire (LPC), Clermont Université, Université Blaise Pascal, CNRS-IN2P3, Clermont-Ferrand, France.

<sup>c</sup>Now at Centro Fermi—Centro Studi e Ricerche e Museo Storico della Fisica “Enrico Fermi”, Rome, Italy.

<sup>d</sup>Now at Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany and Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany.

<sup>e</sup>Now at Sezione INFN, Turin, Italy.

<sup>f</sup>Now at University of Houston, Houston, Texas, USA.

<sup>g</sup>Also at Dipartimento di Fisica dell'Università, Udine, Italy.

<sup>h</sup>Now at SUBATECH, Ecole des Mines de Nantes, Université de Nantes, CNRS-IN2P3, Nantes, France.

<sup>i</sup>Now at Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico and Benemérita Universidad Autónoma de Puebla, Puebla, Mexico.

<sup>j</sup>Now at Laboratoire de Physique Subatomique et de Cosmologie (LPSC), Université Joseph Fourier, CNRS-IN2P3, Institut Polytechnique de Grenoble, Grenoble, France.

<sup>k</sup>Now at Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3, Strasbourg, France.

<sup>l</sup>Now at Sezione INFN, Padova, Italy.

<sup>m</sup>Also at Division of Experimental High Energy Physics, University of Lund, Lund, Sweden.

<sup>n</sup>Also at University of Technology and Austrian Academy of Sciences, Vienna, Austria.

<sup>o</sup>Also at European Organization for Nuclear Research (CERN), Geneva, Switzerland.

<sup>p</sup>Now at Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

<sup>q</sup>Now at European Organization for Nuclear Research (CERN), Geneva, Switzerland.

<sup>r</sup>Also at Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany.

<sup>s</sup>Now at Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany.

<sup>t</sup>Now at Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany.

<sup>u</sup>Also at Fachhochschule Köln, Köln, Germany.

<sup>v</sup>Also at Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia.

<sup>w</sup>Now at Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico City, Mexico.

<sup>x</sup>Also at M. V. Lomonosov Moscow State University, D. V. Skobeltsyn Institute of Nuclear Physics, Moscow, Russia.

<sup>y</sup>Also at Laboratoire de Physique Subatomique et de Cosmologie (LPSC), Université Joseph Fourier, CNRS-IN2P3, Institut Polytechnique de Grenoble, Grenoble, France.

<sup>z</sup>Also at “Vinča” Institute of Nuclear Sciences, Belgrade, Serbia.

<sup>aa</sup>Also at Wayne State University, Detroit, Michigan, USA.

<sup>bb</sup>Also at University of Houston, Houston, Texas, USA.

<sup>cc</sup>Also at Department of Physics, University of Oslo, Oslo, Norway.

<sup>dd</sup>Also at Variable Energy Cyclotron Centre, Kolkata, India.

<sup>ee</sup>Now at Department of Physics, University of Oslo, Oslo, Norway.

<sup>ff</sup>Also at Dipartimento Interateneo di Fisica “M. Merlin” and Sezione INFN, Bari, Italy.



<sup>gg</sup>Now at Nikhef, National Institute for Subatomic Physics and Institute for Subatomic Physics of Utrecht University, Utrecht, Netherlands.

<sup>hh</sup>Also at Institut de Physique Nucléaire d’Orsay (IPNO), Université Paris-Sud, CNRS-IN2P3, Orsay, France.

<sup>ii</sup>Also at Hua-Zhong Normal University, Wuhan, China.

<sup>jj</sup>Also at Centro Fermi—Centro Studi e Ricerche e Museo Storico della Fisica “Enrico Fermi,” Rome, Italy.